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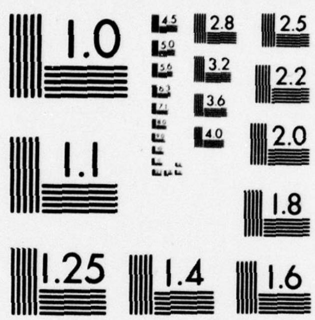

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CRASHWORTHINESS VERSUS COST: A STUDY OF ARMY ROTARY WING AIRCRAFT ACCIDENTS IN PERIOD JAN 70 THROUGH DEC 71.

January December

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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CRASHWORTHINESS VERSUS COST: A STUDY OF SEVERE ARMY ROTARY WING AIRCRAFT ACCIDENTS IN PERIOD JAN 70 THROUGH DEC 71

ABSTRACT

This paper discusses the economic benefits of providing improvements in crashworthiness within future Army aircraft. The crashworthiness improvements considered are those of Military Standard 1290, *Light Fixed- and Rotary-Wing Aircraft Crashworthiness*. The benefits in reduced personnel losses and airframe damage were studied using 299 severe accidents occurring to Army rotary wing aircraft during 1970 and 1971. These accidents were analyzed in detail under a joint USAAAVS/USAARL study effort. The crashworthiness benefits are applied to the Utility Tactical Transport Aircraft System (UTTAS) and projected on a per-flight-hour basis over its lifetime. The total costs of providing these crashworthiness improvements are estimated using a simple model based on aircraft weight. These costs include both initial acquisition costs and recurring maintenance and operating costs. The benefits resulting from the increased level of crashworthiness are then compared with the costs of providing these improvements in UTTAS aircraft. The features which contribute most heavily to the projected personnel and hardware savings are discussed in an estimated order of priority according to their relative cost-effectiveness. Recommendations are made regarding use of the results of this study and possible expansion of the study to other future aircraft systems.

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CRASHWORTHINESS VERSUS COST: A STUDY OF SEVERE ARMY ROTARY WING AIRCRAFT ACCIDENTS IN PERIOD JAN 70 THROUGH DEC 71

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INTRODUCTION

Hugh DeHaven first began to examine the causes of injuries in aircraft accidents at Cornell University in 1942 [1]. DeHaven's early research revealed that unnecessary injuries were occurring in crashes because of poor restraint systems and aircraft cockpit structures. After thirty years, aircraft crash survival studies show that the same causes still exist and cause excessive injuries.

Perhaps one reason why the same mechanisms are still causing injuries is that safety improvements that have been developed over the years, but which were never implemented, were not proposed to aircraft development managers in their "language." One systems management technique which might be used to identify those areas where crash survivability improvement would be most worthwhile, from an overall standpoint, is the analysis of the cost-effectiveness of specific safety features.

This type of analysis is ideally suited for answering the questions which doubting aircraft manufacturers and weight-conscious operators often ask of safety groups: "How much more weight and expense can be added for crash survival? Have we not already added much weight and cost to our aircraft to prevent crashes? Shouldn't our aircraft be designed to fly, not crash? How much more can we spend on crash survival and still market an economically attractive aircraft?"

One reason why a cost-effectiveness approach has not been useful in the past is that very little data concerning the benefits-to-cost comparison of specific crashworthiness features are available. The authors are aware of only three previous documents which yield some of the prerequisite data. Zilioli and Bisgard [2], [3], studied the cost of injuries to US Army aviators in Fiscal Year 1969, but the injuries were not related to aircraft crash protective systems. In 1972, Haley, Sand, and Eagles [4] examined 67 of the 121 accidents used in the Zilioli study. This examination showed that the crash safety features under consideration for the Army's new utility tactical transport aircraft system (UTTAS), the existing UH-1 helicopter replacement, should be cost effective after a service life of about

five years. This information was useful to help justify certain crash safety features of the UTTAS, but the study was based on only a relatively few crashes of one type aircraft.

The purpose of the present study was twofold. First, the study was used to focus on those personnel injury cause factors which are most prevalent in severe aircraft crashes. From this standpoint, this study updates and expands previous Army aircraft crash injury study efforts, such as Ref. [4]. Second, this study attempts to compare the cost to benefits of specific crash safety features. The safety features considered are those required for incorporation into future military rotary wing aircraft by Military Standard 1290 [5].

The authors believe that a cost-effectiveness analysis should not be the only management tool used to study crash safety improvements. Cost effectiveness analysis, for example, would not be the optimal technique for justifying the basic need for crashworthy aircraft. However, this approach does appear reasonable for other purposes, such as choosing the most economical technical alternative (i.e., combination of specific crashworthy features and designs) to meet a given set of requirements. In order to provide the type of crash data required for such studies, a comprehensive and unbiased analysis of crash safety benefits as compared with their cost is undertaken. This paper reports the results of the initial data sample: severe Army rotary-wing aircraft accidents in the period Jan 70 - Dec 71.

NOMENCLATURE AND DEFINITIONS

Aircraft Accident - Damage which occurs to one or more aircraft while flight was intended. Damage as a direct result of hostile fire is not an accident but a combat loss.

Crash - Damage occurring to an aircraft while flight was intended, not including combat losses. In most instances, the terms "crash" and "accident" are interchangeable, except for multiple aircraft accidents (e.g., midair collisions). In these, only one accident occurs, but one crash for each aircraft is considered.

Precautionary Landing - A landing necessitated by failure or impending failure of components which makes continued flight inadvisable, but which did not result in damage.

Forced Landing - A landing necessitated by failure or impending failure of components which makes continued flight impossible, but which did not result in damage.

Major Accident - An aircraft accident is classified major when the aircraft is destroyed, or damage sustained is in excess of prescribed limits as to required repair manhours (e.g., 500 repair manhours for UH-1 aircraft) or a major component (e.g., fuselage section or tail boom) is destroyed beyond economical repair, or the aircraft is lost or adandoned.

Severe Crash - A crash in which major hardware damage was sustained and, in addition, at least one occupant suffered major injuries.

Survivable Accident - An accident in which the following

statements are satisfied for at least one occupant aboard the aircraft:

a. The forces transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations.

b. The fuselage structural container maintains a livable volume around the occupant.

Nonsurvivable Accident - An accident in which neither of the above statements is satisfied for <u>all</u> occupants aboard the aircraft.

Mild Survivable Crash - A crash in which major hardware damage was sustained but in which no major injuries occurred.

Rollover Crash - A crash in which the aircraft fuselage executes at least a 45 deg rotation about its longitudinal axis after initial contact with the ground.

Noseover Crash - A crash in which the aircraft fuselage executes at least a 90 deg rotation forward about a lateral axis after initial ground contact.

Major Impact - The impact which results in the largest deceleration forces transmitted to the aircraft.

Airspeed at Impact - The component of aircraft velocity measured along its longitudinal axis just prior to the major impact.

Vertical Impact Velocity or Sink Speed - The component of aircraft velocity measured perpendicular to the terrain just prior to major impact.

Major Injury - Any injury requiring five days of hospitalization or any of the following symptoms without regard to hospitalization:

a. Unconsciousness due to head trauma.

b. Fracture (open or closed) of any bone, other than closed fractures of the phalanges or nasal bones.

c. Traumatic dislocation of any joint, excluding phalanges, or internal derangement of the knee.

d. Injury to any internal organ.

e. Moderate-to-severe lacerations which cause extensive hemorrhage or require extensive surgical repair.

f. Third-degree burns.

g. First- and second-degree burns involving more than five percent of the body surface.

Thermal Injury - A fatal or non-fatal injury caused by exposure to combustion effects: heat, noxious gas inhalation, and medical complications caused by thermal burns.

Impact Injury - All injury causes other than thermal or drowning.

Crash Force Attenuation - The attenuation of impact force through the medium of structural deformation. The protective fuselage should deform but not collapse. For example, landing gears should absorb energy "limit loads" prior to failure, and occupant seats must "limit" torso decelerations to non-injurious levels.

Unless otherwise specified, other terminology is as defined in Military Standard 1290 [5].

APPROACH

The benefits of specific improvements in aircraft crash survivability are compared with the costs of providing these improvements. The only benefits considered are those which would be attained in severe crashes, in which one or more occupants suffer major injuries. These benefits are based on an analysis of all such accidents which occurred to five Army rotary wing aircraft types during CY 70-71. No benefits are included for less severe accidents.

The aircraft considered in this study are described in Table 1. These include practically all Army rotary wing aircraft with the exception of small, two-place trainer aircraft and the large CH-54 (Sikorsky Skycrane) cargo aircraft (for which insufficient crash data was available).

The Army experienced a total of 1013 accidents to these five aircraft types during the period 1970-1971 (this figure does not include precautionary landings, forced landings or incidents). Severe accidents meeting the criteria specified occurred a total of 299 times during this period (approximately 30 percent of the total); however, these accidents accounted for 100 percent of the total of 818 major injuries and fatalities which occurred. These statistics are presented in Tables 2 and 3 to graphically reveal the relation of this study to the total Army aircraft accident picture in the same time frame.

Tables 2 and 3 indicate that this study should focus on the major injury producing mechanisms in aircraft accidents. However, this technique will result in highly conservative estimates for hardware damage reductions since it is anticipated that the greatest relative contribution to the total hardware savings will be in the less severe accidents (the 70 percent not included in this study). All benefits are ignored for these less severe accidents.

From a humanitarian standpoint, the major goal of crash safety improvements is a reduction of major personnel injuries. The reduction in hardware losses is "icing on the cake." Army experience shows that these hardware losses are an important economic consideration, however, and they are included in this study for the applicable severe crashes.

The sum of these personnel and hardware benefits is compared with an estimate of the total costs involved in providing these improvements in the Army's fifteen-place Utility Tactical Transport Aircraft System (UTTAS), currently in prototype development. An estimate is made of the time required for the total improvements called for in Military Standard 1290 to "pay for themselves" in decreased losses.

In addition, those components/features which contributed most heavily to projected savings are identified. This type of information is considered particularly important for use by the aircraft system project manager in future decisions regarding optimum crash safety versus cost/weight reduction efforts.

Table 1. US Army Aircraft Included in Present Study

Aircraft		Configuration	Maximum Takeoff Weight (lbs)	Crew	Pass.
AH-1G "Cobra"	Attack, close air support	Single main rotor; single gas turbine engine; tandem crew seating	9,500	2	0
CH-47A/B/C "Chinook"	Transport of troops and cargo	Tandem main rotors; twin gas turbine engines	33,000-46,000*	4	33
OH-6A "Cayuse"	Observation	Single main rotor; single gas turbine engine	2,700	2	2
OH-58A "Kiowa"	Observation	Single main rotor; single gas turbine engine	3,000	2	2
UH-1D/H "Iroquois"	Utility	Single main rotor; single gas turbine engine	9,500	2	11

*Depends on specific model and series

Table 2. Summary of CY 70-71 Army Aircraft Accidents, Five Aircraft Types

Aircraft	Flying hours	Total major crashes	Mild, surviv- able crashes	Severe, surviv- able crashes	Nonsur- vivable crashes	Ratio of nonsurviv- able to total crashes
AH-1	619,164	154	92	24	38	.25
CH-47	405,488	43	20	14	9	.21
OH-6	597,327	217	171	42	4	.02
OH-58	467,854	77	59	11	7	.09
UH-1	3,578,443	522	372	107	43	.08
Total, CY 70-71	5,668,276	1,013	714	198	101	.10
Total in this study	5,688,276	299*	0	198	101*	.34*

Table 3. Summary of CY 70-71 Injuries in Army Aircraft Accidents, Five Aircraft Types

Aircraft	Total major crashes	Total aboard	Total casualties	Occupants in severe, survivable crashes	Casualties in severe, survivable crashes
AH-1	154	303	137	48	42
CH-47	43	457	356	151	119
OH-6	217	516	182	110	104
OH-58	77	190	64	31	27
UH-1	522	3,106	1,085	714	497
Total, CY 70-71	1,013	4,572	1,824	1,054	818
Total in this study	299	1,054	818	1,054	818

*Nonsurvivable accidents used only in Figures 3, 4 and 5 to study impact velocities in survivable and nonsurvivable conditions.

Analysis of Individual Accident Cases

In the study of individual reports of accident investigations, particular emphasis was placed on a uniform and objective analysis. A preprinted work sheet (Appendix I) was used to summarize each accident. The following accident characteristics were studied:

a. Degree of survivability.
b. Impact kinematics.
c. Terrain characteristics and features of the crash sequence.
d. Total aircraft damage versus what damage was considered preventable using improved crashworthiness technology.
e. Occupant location.
f. Occupant injury (type and degree).
g. Summary of injuries which would have been preventable.

The authors analyzed each accident report. Wherever possible, the result of the accident analysis, as contained in the completed work sheet, was reviewed independently by the other author. The completed summaries generally represent a consensus of opinion. This technique minimized the subjectivity of the results.

During analysis of the losses which would be preventable by improved technology, a conscious effort was made toward conservatism. No benefits were "claimed" unless a reasonably clear-cut case was apparent.

Rationale for Determining Crashworthiness Benefits

The primary rationale used to determine the benefits of improved crashworthiness is discussed in US Army Air Mobility Research and Development Laboratory Technical Report 71-22 [6]. Crashworthiness requirements for military helicopters are specified in Military Standard 1290 [5]. A brief outline of these requirements compared with the capabilities/requirements of the five aircraft of this study is shown in Table 4.

Personnel Injury Benefits

Injuries and/or fatalities caused by any of the following factors were considered potentially preventable:

a. Restraint system failure such as a complete separation of harness or seat from moorings.
b. Inadequate crash force attenuation (injury resulted from excessive overall decelerative forces).
c. Torso impact by flailing, i.e., "near flung" missile. (Flailing injuries may be prevented or reduced by use of low-elongation webbing and/or padding requirements).
d. Crushing by inward buckling of fuselage.
e. Crushing by transmission penetration of fuselage.
f. Crushing by penetration of liveable volume by main rotor blade, tree limbs, etc.
g. Burns due to post-crash fire.
h. Impact by cargo which was inadequately tied down.

Table 4 Crashworthiness requirements of MIL STD 1290 compared to current Army aircraft

ITEM	TYPICAL CURRENT DESIGN	MIL STD 1290	POTENTIAL INJURY OR HARDWARE DAMAGE REDUCTION/ELIMINATION
LANDING GEAR	Sink speed capacity (zero fuselage deformation) = 12-15 ft/sec with zero-degree roll and pitch	Sink speed capacity = 20 ft/sec with 10-degree roll and pitch	. Vertical crash force injury . Reduces rollovers which reduces hardware damage and flail injury
PERSONNEL RESTRAINT HARNESS	Shoulder straps not used on seats other than pilot seats (except OH-6 and OH-58)	. Shoulder straps required . Convenient ingress-egress . Low-stretch webbing	. Head and upper torso "flail" injuries
SEATING	Ultimate loads (total restraint system): . Pilot = 12-20G_x, 6-10G_y, 15G_z . Other = 10G_x, 5G_y, 11G_z	. Pilot - 30G_x, 20G_y, 15G_z . Other - 24G_x, 20G_y, 15G_z . "Limits" G loads to survivable levels	. Spinal column compression fractures and other internal injury . Torso ejection from fuselage
FUSELAGE INTEGRITY	. Rollover integrity is fair . Large side openings reduce strength and integrity of UH-1D/H	. Rollover strength is better . Cockpit structure sustains 4G times aircraft weight at any loading angle	. Injuries caused by inward fuselage buckling
MAIN TRANSMISSION INTEGRITY	Tie-down strength, applied separately: . OH-6 = 17G_x, 17G_y, 20G_z . OH-58=15G_x, 10G_y, 20G_z . Remainder = 8G_x, 8G_y, 8G_z	Tie-down strength, applied in selected combinations: 20G_x, 18G_y, 20G_z	. Injuries caused by transmission/rotor penetration of cabin . Structure damage due to displaced transmission
MAIN ROTOR BLADE INTEGRITY	Rotor hub-to-mast integrity for flight loads only, except OH-6 static mast which provides good crash integrity	Better hub-to-mast integrity (Rotor must not displace excessively when outer 10% span torn off).	. Injuries caused by blade penetration . Structure damage due to displaced rotor
TAIL ROTOR	Tail rotor vulnerable to impact by trees and other obstacles	. Tail rotor protected from impact by location and shielding . Blades are impact tolerant	. Eliminates many accidents caused by tail rotor strikes. . Eliminates loss of anti-torque control after blade strike

i. Impact with interior of aircraft structure ("far-flung" missile injuries) because no seat was provided for the occupant.
j. Other factors were specified as appropriate, such as personnel restraint system provided but not used.

Each individual casualty was studied to determine if, in fact, there was a reasonable probability that the major injury in each case could have been prevented and to what specific crash safety improvement the benefit was attributable. The results of this analysis highlighted those areas where the greatest relative benefit can be attained in applying the requirements of Military Standard 1290.

In those cases where crash forces were very severe, as in partially survivable accidents in which only a portion of the occupiable area was survivable, the potential to prevent injuries was considered for only the survivable portion.

Hardware Benefits

Based on the reported list of parts/components to be repaired or replaced versus what components would be protected from damage if the requirements of Military Standard 1290 had been applied, an estimate was made of the hardware benefits of crashworthiness design in each accident. Early in the study it became apparent that it is extremely difficult to single out specific crashworthy features (e.g., improved landing gear, increased transmission tie-down strength) which would result in specific amounts of hardware savings. The various mechanisms of hardware damage and techniques of preventing this damage are too varied and inter-related for specific improvements to be detailed for each crash. For these reasons, the only estimate of hardware benefits which could be made was an overall estimate of all savings resulting from Military Standard 1290 guidance taken as a whole.

Whereas it is anticipated that the greatest injury benefit would be attained in severe accidents of the type studied here, the greatest savings in hardware damage may be attained in the relatively mild impact. Various abnormal landings are much more frequent than these severe accidents and cause significant hardware damage but relatively few of the occupant injuries. These may be entirely sustained with little or no damage by aircraft designed in accordance with Military Standard 1290. But, as mentioned before, these benefits were ignored for the purposes of this study. Therefore, estimates of total hardware savings based on the accidents studied here are considered very conservative.

Rationale for Comparison of Benefits with Costs

A cost effectiveness analysis of improved crashworthiness requires a comparison of the <u>total</u> benefits with the total costs over the life cycle of the aircraft. The total crash safety benefits were estimated by summing the personnel and hardware savings from the severe accidents studied. These savings were related to the projected

experience of the Army UTTAS aircraft using current Army planning figures for UTTAS acquisition costs and usage rates. Crash safety benefits were projected using a range of anticipated accident rates.

The total costs to provide these improvements include all fixed and variable costs associated with developing, procuring, maintaining and operating the necessary hardware. For a commercial aircraft, an important part of these costs would also be a reduction in profits due to a decreased payload capacity of the aircraft. For the Army UTTAS, costs associated with procurement, maintenance and operation as estimated by the UTTAS aircraft project manager were used. That portion of the total costs due to increased crashworthiness was estimated as a simple ratio of the estimated weight of the crashworthy features to the total aircraft weight empty. This provided a very simple but conservative estimate of the total life cycle costs to provide Military Standard 1290 crashworthiness in the UTTAS aircraft.

The costs of providing these improvements was then compared with the benefits to be gained to determine the length of time required for the crashworthy hardware to "pay for itself." The benefits of the specific components/features required by Military Standard 1290 were then weighed against each other in order to obtain an order of priority for the crashworthy features.

RESULTS

Introduction

A total of 299 crashes as indicated in Table 2 were examined and each was recorded on a data sheet (Appendix I). Of the 299 crashes, 198 were classed as survivable. Only these crashes were examined to determine cost effectiveness, because it was more difficult to decide whether crashworthy features would have made significant injury and hardware damage reductions in crashes classified as "nonsurvivable". Results of this study are illustrated in tables and figures.

Terrain

The terrain involved in these crashes is graphically shown in Figure 1. It is evident that terrain hazards were involved in most (70 percent) of these severe crashes. Only one type of terrain or obstacle at the point of major impact was recorded for each crash, i.e., that obstacle or terrain which caused the major damage to aircraft and occupants. Terrain hazards, excluding "hard surface" were recorded in 59 percent of these accidents. Whether or not "water" should be considered a hazard is questionable, but many drownings did occur and it is listed as such. It should be noted that a majority of the accidents represented in Figure 1 occurred in the Republic of South Vietnam (RVN), and that the results could vary for other locales.

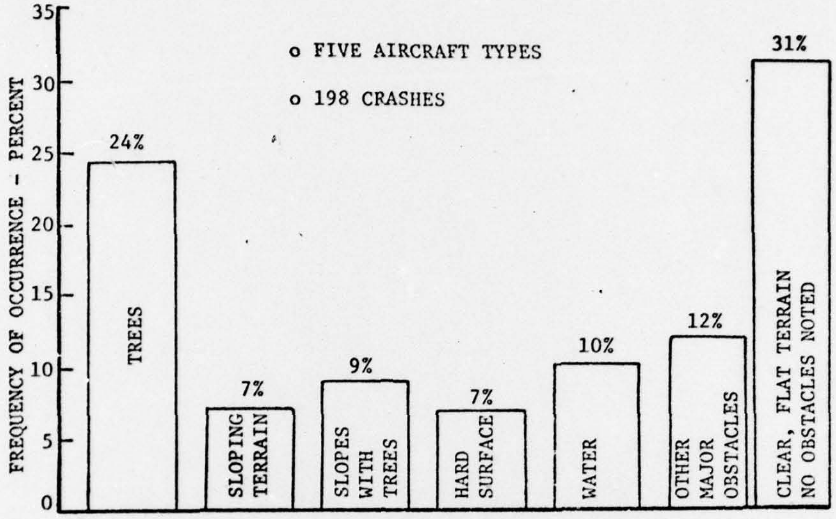

Fig. 1. Terrain hazards in survivable crashes

Impact Kinematics

Crash Sequence Hazards

Figure 2 shows frequency of occurrence of: (a) rollover impact, (b) noseover impact, (c) sideward impact, (d) severe plowing, and (e) inverted impact. Note that the rollover crash was by far the most frequent occurrence. Only the AH-1 showed a relatively low (25 percent) rollover rate. The stub wings of the AH-1 probably prevented it from rolling as often as the others. This data shows that the rollover crash hazard should receive high priority in crashworthy design.

Crash Velocities

The velocity at the instant of major impact was estimated from one or more of the following factors: (a) recorded value from accident report as determined from witnesses or board estimate, (b) structural deformation observed in photographs, (c) comparison of crash to similar instrumented full-scale crash tests, and (d) type and degree of personnel internal injuries. The vertical impact velocity (sink speed) is compared to the simultaneous airspeed at the instant of major impact in Fig. 3, 4, and 5 for the UH-1, OH-6 and AH-1 helicopters. Nonsurvivable cases are shown in these figures for reference only. Velocity data are not shown for the OH-58 and CH-47 due to the small number of cases.

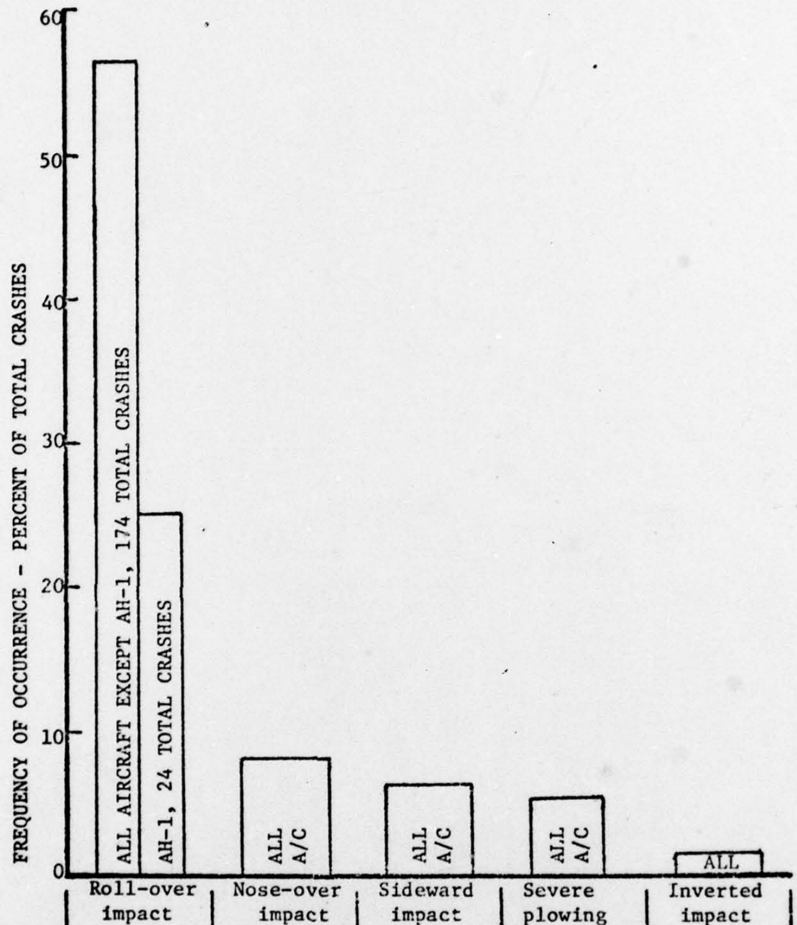

Fig. 2. Crash sequence hazards, total of 198 crashes

To make the 107 UH-1 crash velocities of Fig. 3 more useful, a statistical 95th percentile limit has been calculated. These limits were calculated by breaking the airspeed into intervals of approximately 20 feet per second. The 95th percentile vertical impact velocity within each of these airspeed intervals was then calculated. An estimate for the survivability limits was then made by plotting each 95th percentile vertical velocity with its corresponding airspeed (taken as the midpoint of the appropriate interval). The same procedure was then applied using intervals of vertical velocity. These two estimates for the variation of survivability limits with airspeed and sink speed were then graphically averaged to determine the best estimate for the 95th percentile limits.

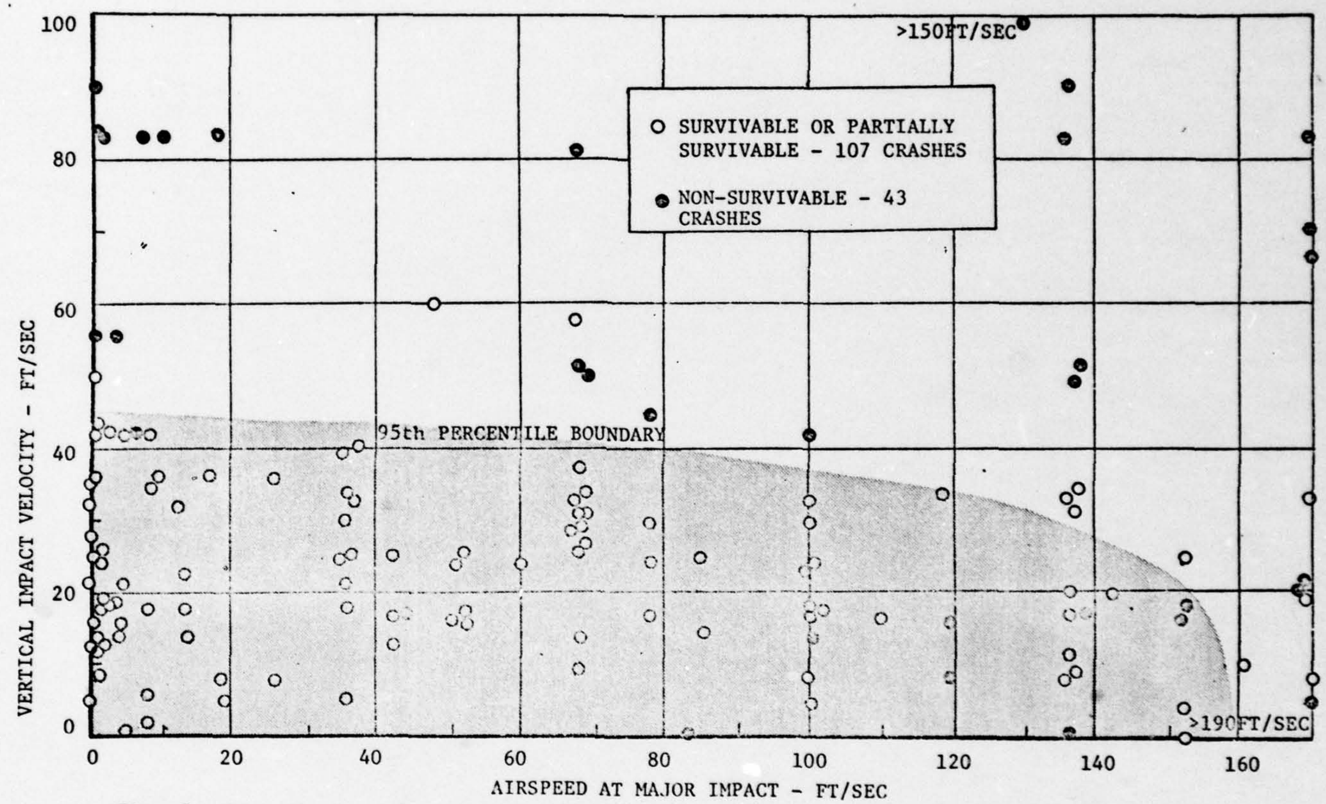

Fig. 3. Distribution of UH-1 impact kinematics and 95th percentile survivable limits

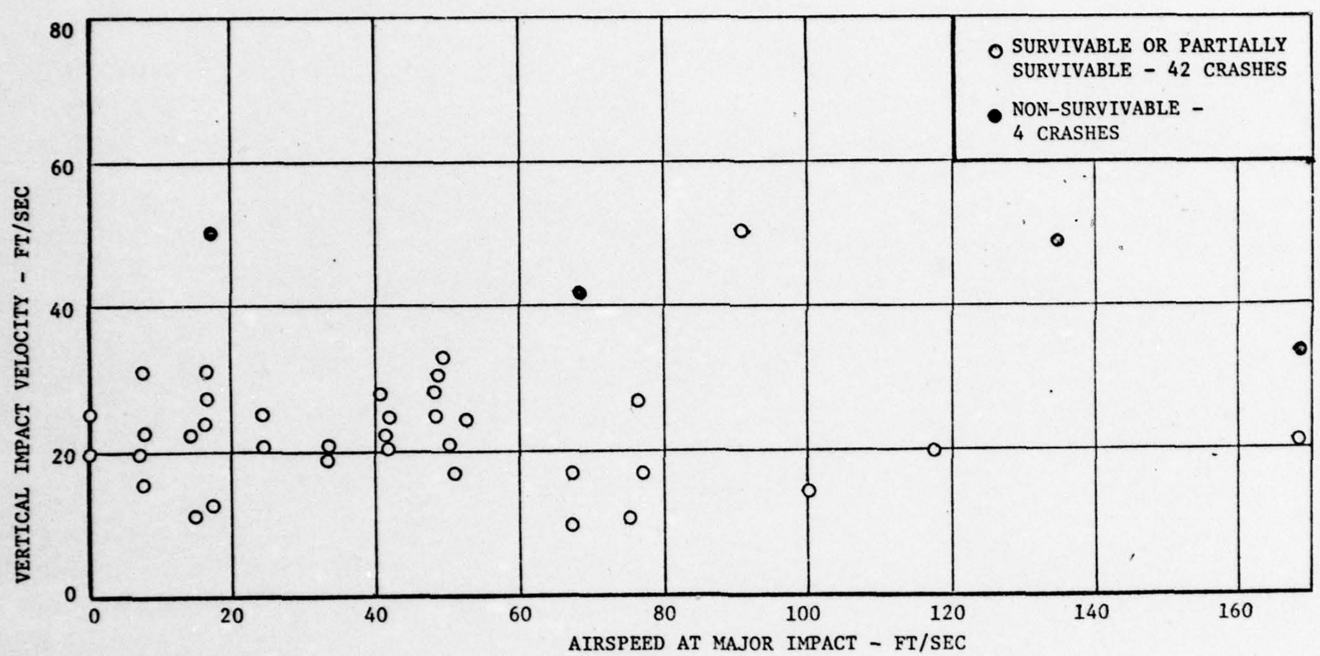

Fig. 4. Distribution of OH-6 impact kinematics.

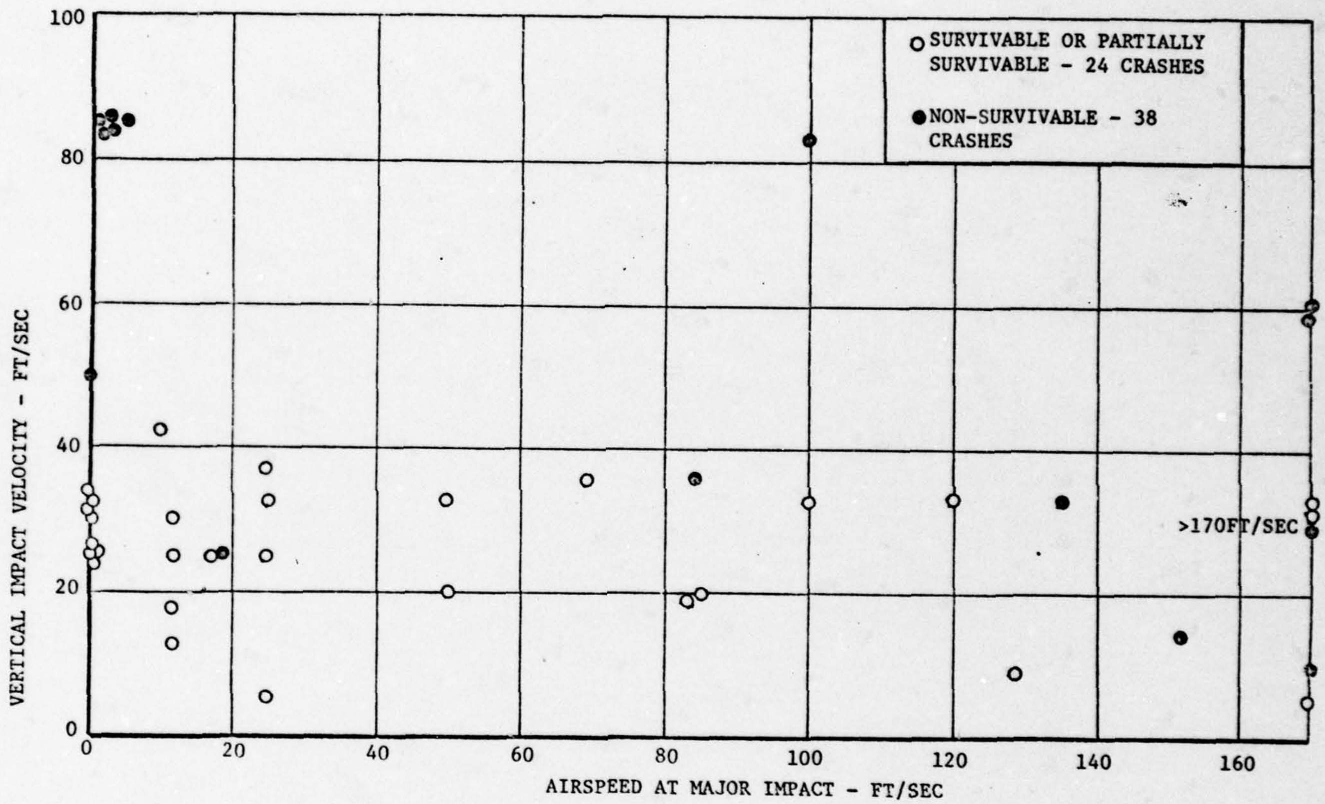

Fig. 5. Distribution of AH-1 impact kinematics

Fig. 3 depicts the broad range of impact conditions (airspeed and vertical velocity) which were present in UH-1D/H crashes. The survivability limits shown are a basic measure of aircraft crashworthy design. This measure represents the basic criteria under which improvements in occupant survival must be evaluated. For example, a crashworthy troop seat should be designed to sustain the impact loads present in the fuselage during such crash conditions. Anything less would not take full advantage of the airframe's crashworthiness. Fig. 3 also demonstrates that it is the combination of airspeed and sink speed which determines impact survivability. Impact airspeeds up to 100 knots (169 feet per second) were survivable when the sink speeds were low (i.e., shallow impact angle). On the other hand, vertical sink speeds of 2,500 feet per minute (42 feet per second) were survivable when the airspeed was quite low.

Effect of Rollover Crashes on Fatalities and Post-crash Fire

The influence of roll-over conditions on the incidence of fatalities and postcrash fire was studied. The number of fatal crashes (a crash in which one or more fatalities occur) and postcrash fire crashes under roll-over and no-roll conditions are shown in Table 5. A total of six UH-1 crashes, in which crashworthy fuel tanks were installed, were deleted from Table 5, because accident records have shown that postcrash fire is unlikely to occur with the crashworthy tanks and the postcrash fire comparison would be less valid. Fatalities occurred in 49 percent (one of two) of roll-over crashes but only 32 percent (one of three) of no-roll crashes. Postcrash fire occurred in 33 percent of roll-over crashes but only 28 percent of no-roll crashes. These results showed that the incidence of fatalities and fire increased in the roll-over crash.

Table 5. Effect of Roll-Over Crashes on Postcrash Fire/Fatalities

	AIRCRAFT IDENTITY	NUMBER CRASHES	NUMBER FATAL CRASHES	PERCENT FATAL CRASHES	NUMBER POSTCRASH FIRES	PERCENT POSTCRASH FIRES
ROLL-OVER CRASHES	CH-47	6	3	50%	4	67%
	UH-1	64	35	55%	19	30%
	AH-1	6	1	17%	0	0%
	OH-6	22	9	41%	8	36%
	OH-58	6	3	50%	3	50%
	Overall	104	51	49%	34	33%
NO-ROLL CRASHES	CH-47	8	4	50%	6	75%
	UH-1	43	17	40%	12	28%
	AH-1	18	2	11%	2	11%
	OH-6	20	4	20%	5	25%
	OH-58	5	3	60%	1	20%
	Overall	94	30	32%	26	28%
	TOTAL	198	81	41%	60	30%

Impact Velocity vs Injury and Fatality Rate

Effect of Vertical Impact Velocity

The primary personnel injury which occurred as a result of vertical velocity was back injury. The distribution of all types of back injury as a function of vertical impact velocity is shown in Fig. 6. The data shows clearly that probability of back injury at sink rates less than 15 feet per second is very low.

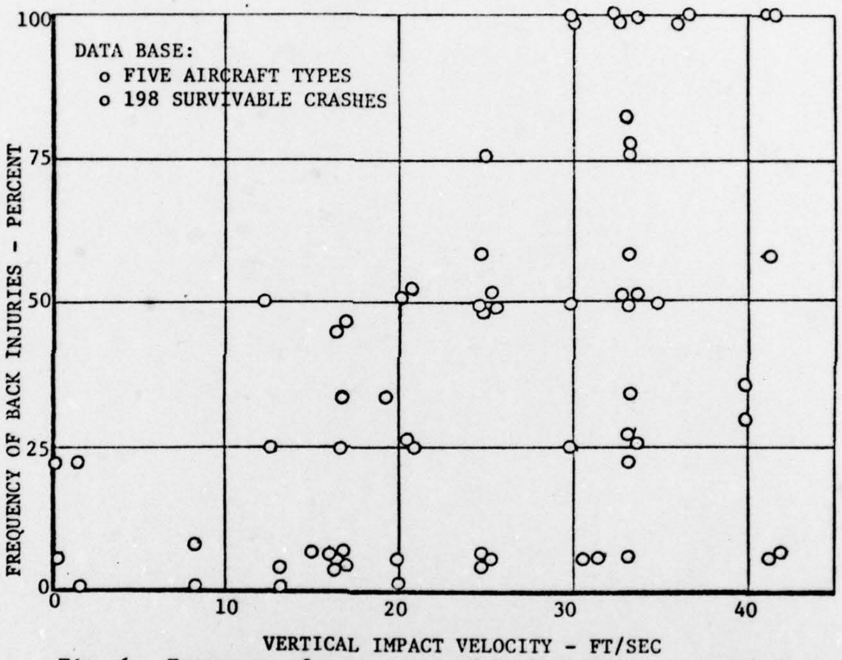

Fig. 6. Frequency of occurrence of back injuries vs vertical impact velocity, based on 198 crashes

Effect of Impact Airspeed

The frequency of occurrence of injuries and fatalities as a function of airspeed is graphically depicted in Fig. 7. Note that the ratio of fatalities to total people aboard increases from four percent to forty percent as airspeed increases. On the other hand, the ratio of injuries to total aboard remains essentially constant with airspeed. The helicopter's tendency to "jump like a football" during low velocity impacts causes many injuries. This bouncing, rolling, and/or leaping during impact are caused by a relatively high c.g., fixed-skid landing gears, and lifting rotors which "bite" earth and result in rotation or complete rollover. In essence, this data shows the injury potential of helicopter passengers in low impact speed crashes, and it also demonstrates that higher crash velocities cause more fatalities.

The data in Fig. 6 and 7 support the design requirements of Military Standard 1290 as outlined in Table 4. For example, landing gears should nearly eliminate the back injuries shown in Fig. 6, while the requirements for stronger seats, transmissions, rotors, and fuselage structure should reduce the number of fatalities and injuries emphasized in Fig. 7.

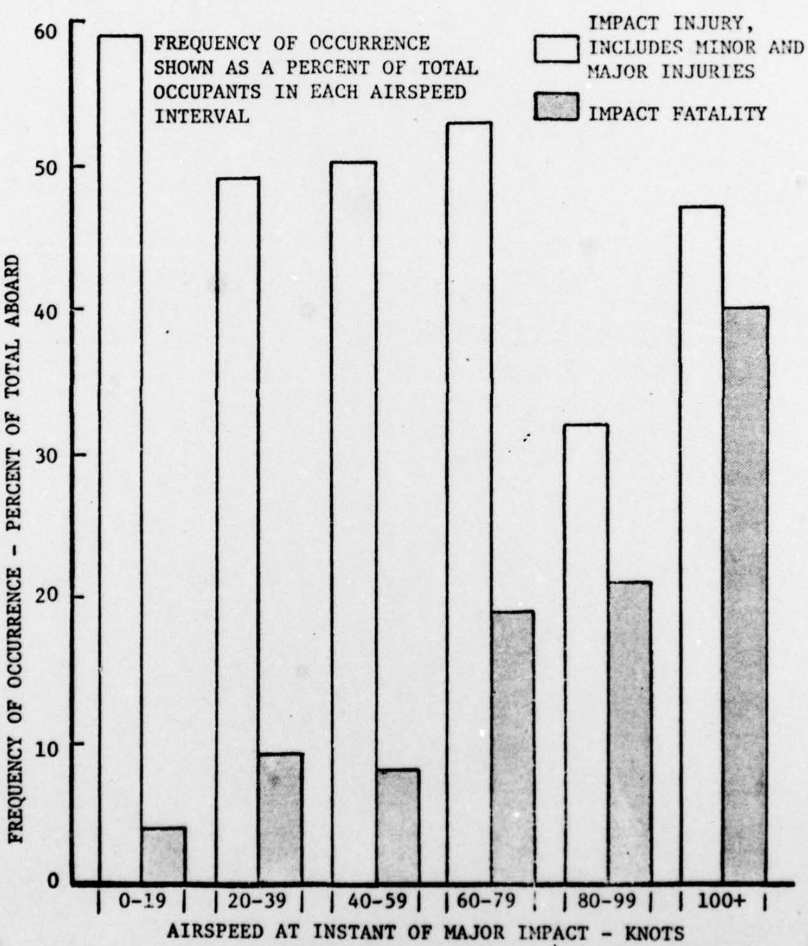

Fig. 7. Injury and fatality occurrence as a function of airspeed at impact

Injury Classification and Causes

Injury Classification

Figure 8 shows the total number of casualties (includes all injuries and fatalities, a portion of which could have been prevented by improved crashworthiness) as a percent of those aboard. The casualities are classified as either: impact, fire, or drowning. It is clear that impact forces caused a majority of the injuries and fatalities.

It may be surprising to note that drownings caused 36 deaths. A majority of these drownings occurred because of a simple inability to swim, while the rest occurred because of incapacitating impact trauma which prevented escape. Only the latter type drowning fatalities were considered "preventable" by improved crashworthy design features.

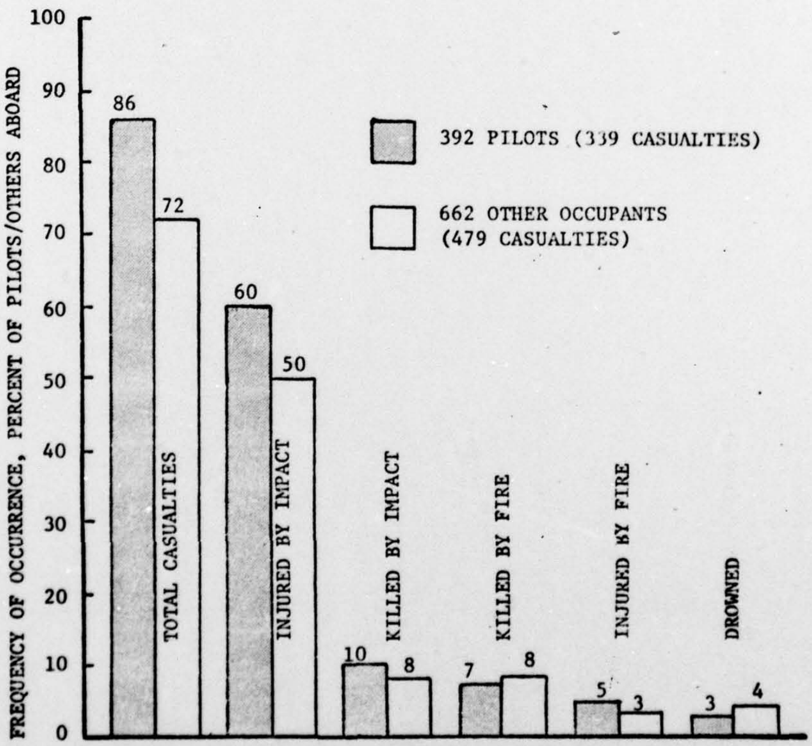

Fig. 8. Occupant injury classification

Poor Crashworthy Features Causing Preventable Injuries

The features most significant as unnecessary injury producers are shown in Fig. 9 and 10. Fig. 9 shows poor crashworthy features responsible for potentially preventable injuries and Fig. 10 shows the same features responsible for preventable fatalities. These agents are discussed below:

a. Postcrash fire - this one factor caused more preventable fatalities than any other.

b. Poor restraint system - poor restraint caused more unnecessary fatalities than any other factor excluding postcrash fire. Poor restraint means that occupant seat and harness were: (a) not complete (i.e., no shoulder strap, etc.), (b) not strong enough, (c) of improper geometry, or (d) not accompanied by sufficient padding in torso flail area.

c. Crash force attenuation - this agent was a primary injury producer and a significant fatality producer.

d. Inward buckling/crushing of fuselage - this factor caused only eight preventable fatalities and eight injuries. These relatively low values are somewhat misleading. One must be aware that many accidents were classified nonsurvivable due to general inward buckling and crushing of the structure which eliminated livable space. The fact that few buckling/crushing crashworthy "benefits" were considered shows the degree of conservation used in this study, because the crashworthy UTTAS is expected to prevent inward buckling/crushing at higher impact speeds.

e. Fuselage penetration by rotor blades, transmission, or trees - denotes penetration of fuselage structure by named objects to extent necessary to actually cause injuries to occupants. This factor caused four fatalities and one injury. This low injury rate may be misleading. Rotor blade displacement, with potential to cause injury if all seats had been occupied, was noted in seven of the 107 UH-1 crashes. In general, displacement of the transmission and rotor mass can result in the following hazards: (a) potential trauma to occupants, (b) severance of flammable fluid lines (c) severance of electrical lines, (d) severance of flight controls, and (e) spillage of hot transmission oil near engine inlets.

f. No seat provided - denotes when no seats were available, either by design omission or operational deletion. This factor caused four fatalities and two injuries.

g. "Other" causes - This factor caused three fatalities and two injuries.

h. Poor cargo tie-down - denotes deficient tie-down of cargo with the devices provided. One fatality and two injuries were sustained by this mechanism. Poor cargo tie-down may have caused more injuries than those recorded by accident boards. For example, incapacitating injuries may have been caused by displaced cargo prior to death by postcrash fire.

The agent (Restraint Provided, Not Used) was also a primary injury producer and a significant fatality producer for "other" personnel. Nevertheless, this factor was not considered a preventable injury. Undoubtedly, accidents will continue to occur in "crashworthy" aircraft, and available restraint harnesses will not be used.

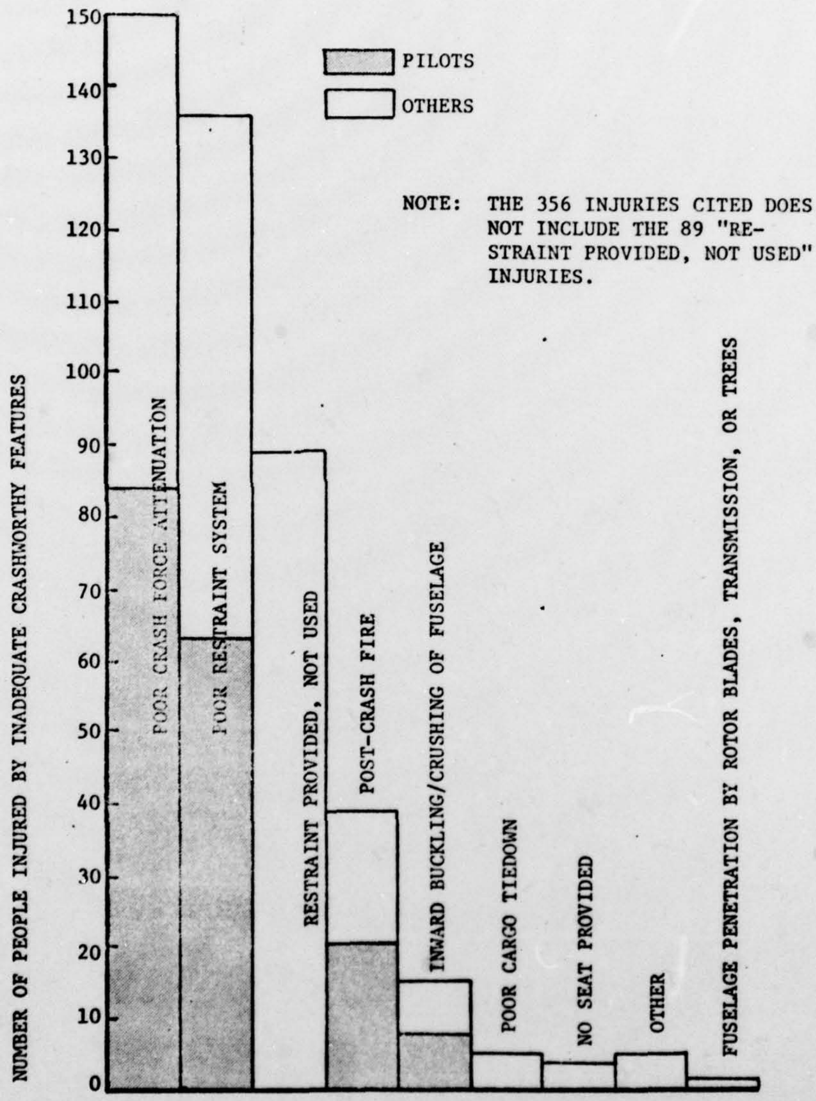

Fig. 9. Identity of hardware deficiencies causing 356 potentially preventable injuries

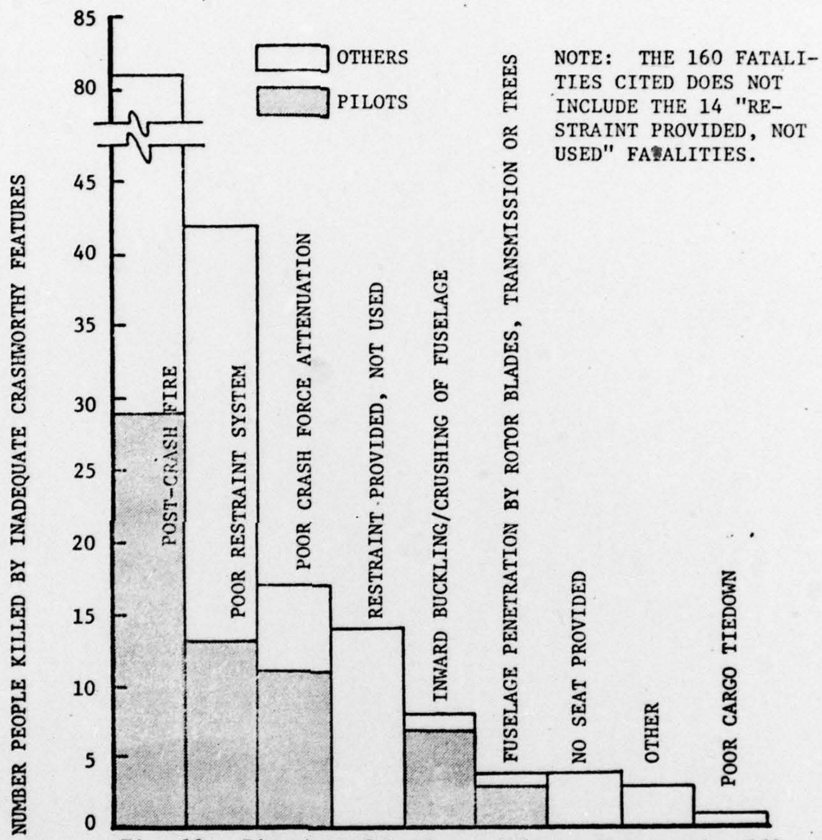

Fig. 10. Identity of hardware deficiencies causing 160 potentially preventable fatalities

Summary of Benefits and Costs

Potential Occupant Injury Savings by Use of Crashworthy Features

Fig. 9 and 10 have shown that 160 fatalities and 356 injuries could have been prevented had the five aircraft of this study been equipped with crashworthy features as outlined in Table 4. The potential dollar savings possible by elimination of these casualties is shown in Table 6. The table shows that approximately 20 million dollars savings were possible in the two year span of this study.

Table 6. Potential Personnel Loss Savings Summary

		US ARMY COST PER PERSON (AVG VALUE) [7]	NUMBER PEOPLE	POTENTIAL SAVING (DOLLARS)
Fatalities	Pilots	$155,000	63	$ 9,765,000
	Others	70,000	97	6,790,000
	Total	--	160	$16,555,000
Injuries	Pilots	$ 15,500	178	$ 2,759,000
	Others	6,000	178	1,068,000
	Total	--	356	$ 3,827,000
Grand Total		--	516	$20,382,000

Potential Aircraft Hardware Savings

Potential hardware savings are tabulated in Table 7. The total loss and potential savings for each of the five aircraft are shown. Note that the savings are about 32 percent of the total hardware losses.

Table 7. Potential Hardware Savings Summary

AIRCRAFT	TOTAL HARDWARE LOSS (DOLLARS)	PREVENTABLE LOSS/ SAVINGS (DOLLARS)
AH-1G	$ 7,370,000	$ 3,520,000
CH-47 A, B, & C	19,997,000	4,150,000
OH-6A	4,162,000	1,232,000
OH-58A	1,092,000	265,000
UH-1 D & H	25,279,000	9,387,000
Total	$57,900,000	$18,554,000

$$\frac{\text{Total Hardware Savings}}{\text{Total Hardware Losses}} = 32 \text{ percent}$$

Total Crashworthiness Benefits (Occupant and Hardware Savings) for UTTAS

In order to relate the personnel and hardware savings shown in Tables 6 and 7 to future aircraft design such as the new Army UTTAS, pertinent facts and assumptions were needed. These facts and assumptions were obtained through the courtesy of the US Army UTTAS Project Manager's Office[8]:

Type aircraft - 15 place, twin-turbine, single main rotor, wheel landing gear
Design gross weight - 15,550 pounds
Design empty weight - 10,025 pounds
Projected useful life - fifteen to twenty years
Procurement cost - \$988,000 each
Operating hours per year - 828
Operating cost per flight hour - \$136 (does not include cost of crew, crew training and indirect support)
Weight of crashworthy features - 339 pounds[9]

To relate crashworthiness cost effectiveness to new aircraft, the savings per flight hour of the five study aircraft were determined. These five aircraft types accumulated 5,668,276 flight hours in the two year span. The potential crashworthy savings which could have been accrued were:

$$\text{Personnel savings per flight hour} = \frac{\$20,382,000}{5,668,276\ \text{hr}} = \$3.60$$

$$\text{Hardware savings per flight hour} = \frac{\$18,554,000}{5,668,276\ \text{hr}} = \$3.27$$

Total personnel injury benefits per flight hour for UTTAS are assumed to be equal to those calculated for the study aircraft. This is a conservative approach since the UTTAS has a slightly larger seating capacity (15-place versus approximately 12-place for the weighted average study aircraft) and personnel savings should be proportional to occupants aboard.

Crash damage (hardware) savings are assumed to be proportional to aircraft acquisition costs; thus UTTAS potential crash damage savings are a ratio of the UTTAS acquisition cost to the cost of the aircraft used in this study. The average "weighted" acquisition cost of the five study aircraft was 312,000 dollars; therefore, the ratio of hardware savings is:

$$\frac{\$988,000}{\$312,000} \times \$3.27 = \$10.36 \text{ per UTTAS flight hour}$$

The total UTTAS personnel and hardware savings are:

Personnel injury	\$ 3.60 per flight hour
Crash damage	\$10.36 per flight hour
Total	\$13.96 per flight hour

Total Crashworthiness Costs for UTTAS

Increased UTTAS acquisition cost due to crashworthiness. After some discussion with helicopter manufacturers, it appears logical to simply assume that crashworthy structural features cost an equal amount per unit weight to the remainder of the aircraft mass. On this basis, UTTAS cost per pound is: $988,000÷10,025lb. = $98.55 per pound.

Thus, UTTAS crashworthy items = 339 lb (98.55) = $33,409

Increased UTTAS operating costs due to added crashworthiness weight. Operating costs are assumed to vary directly with (all-up flying) design gross weight. The extra cost of "flying" with 339 pounds more weight is: 339 lb/15,550 lb X $136/hr = $2.96 per flt hr.

Flight hours/elaped time required to reach "break even" point. To determine the break-even point, the crashworthy acquisition costs and increased operating costs are balanced against the potential savings with crashworthy features. Fig. 11 shows savings and costs per aircraft as a linear function of elapsed time. This "crashworthy savings" line illustrates the fact that money is saved for each accident event, and that for a fixed accident rate, the function is linear with time. If the accident rate is reduced, the "crashworthy savings" line has a reduced slope. The total costs associated with crashworthy features in the UTTAS at any point in time are found by adding the "operating costs" to the "fixed acquisition cost" line. For example, the total added cost of providing crashworthy features in the UTTAS at the end of, say, five (5) years, is $45,600. Of course, the point at which the "crashworthy savings" line intersects the "operating and acquisition" line is the "break even" point at which savings balance costs. This point is 3.7 years elapsed time for the 1970-71 Army accident rate. If the accident rate is reduced 50 percent, the lower "savings" line is applicable, and the break even point is extended to 10.2 years.

The data in Fig. 11 are based on 828 flight hours per year per aircraft. If flight hours per year are lower, the break even point is extended. If flight hours per year are increased the break even point is shortened. For example, if we assume U. S. Army '70-'71 accident rates, at 1,000 flight hours per year the break even point is 2.9 years; whereas for 500 flight hours per year the break even point is 7.4 years.

The above analysis shows that crashworthy features, for military UTTAS type aircraft, can be cost effective in three to ten years, depending on utilization rates and accident experience. These times are well within the projected life span of the UTTAS of fifteen to twenty years.

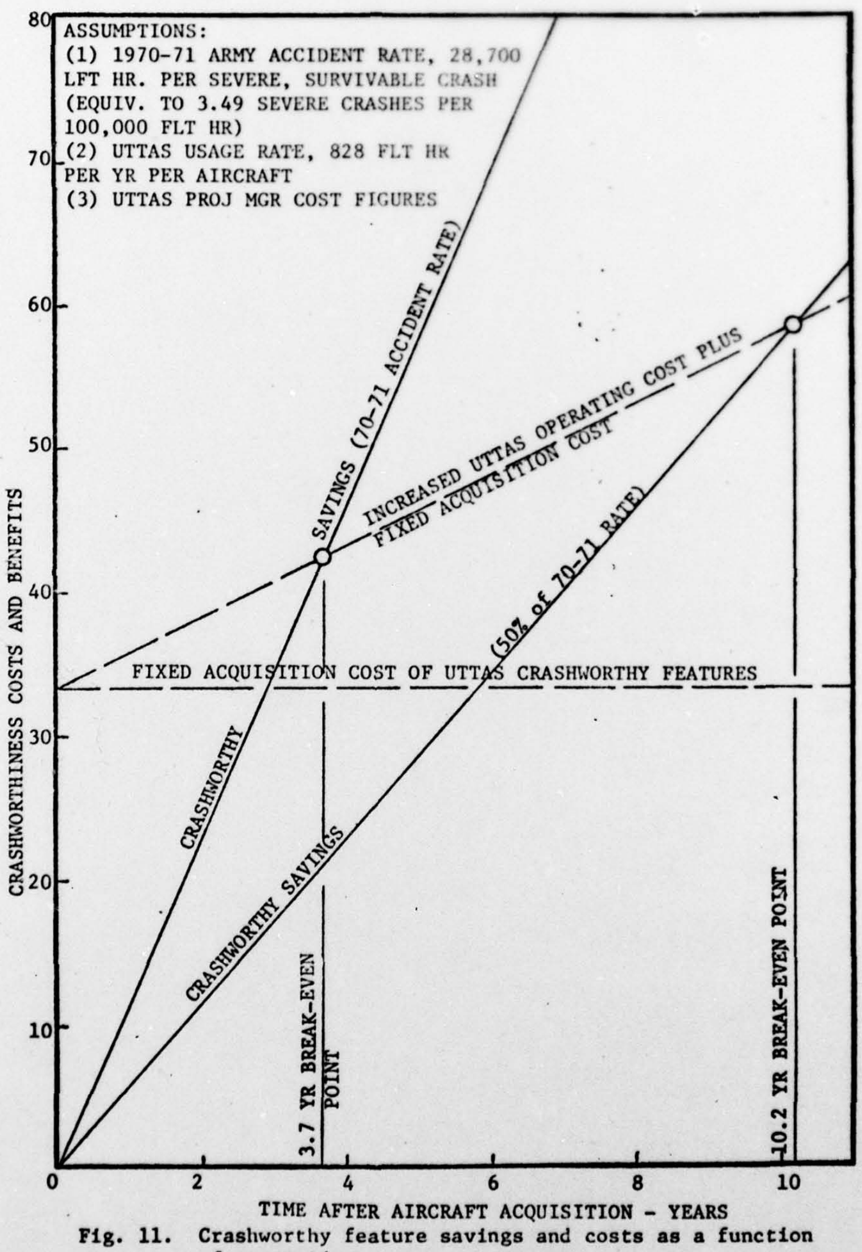

Fig. 11. Crashworthy feature savings and costs as a function of usage time

It is reiterated here that the results of this analysis are conservative for two major reasons:

(a) No savings were considered for the minor occupant injuries and the major hardware damage which occurred in 714 crashes (70 percent of all crashes in the 70-71 time span). The numerous minor injuries would not have summed to large savings, but the major "preventable" hardware damage is believed to be a large sum, because much of this damage could have been prevented by the same crashworthy features considered in this study. The total hardware damage in all accidents in this time frame was three times the total damage in the severe crashes studied.

(b) No savings were considered for occupant injuries in "nonsurvivable accidents. Some of these accidents will be survivable in more crashworthy aircraft.

CONCLUSIONS

a. Crashworthy requirements, as outlined in Military Standard 1290 [5], are cost effective for the military UTTAS helicopter. The initial and recurring costs, as estimated in this report, are amortized in three to ten years.

b. The specific features of Military Standard 1290 which will contribute most heavily to the reduction of severe personnel injuries in the UTTAS aircraft (not considering the costs of providing these features) are:

(1) Crashworthy fuel system

(2) Improved personnel restraint system

(3) Improved crash force attenuation (landing gear and lower fuselage structure)

c. The most worthwhile crashworthy features which influence the prevention/and/or reduction of occupant injuries and hardware damage are listed in an estimated order of priority according to their relative cost-effectiveness:

REDUCTION OF OCCUPANT INJURY	REDUCTION OF HARDWARE DAMAGE
1. Improved occupant restraint, especially upper torso, to prevent flailing injuries.	1. Protected tail rotor with impact tolerant blades will prevent many accidents.
2. Fuselage rollover capability without collapse.	2. Improved landing gear to prevent rollover, as well as greater absorption of sink speed energy.
3. Improved landing gear to prevent snagging/gouging and resultant rollover, as well as greater absorption of sink speed energy.	3. Impact-tolerant main rotor blade tips and transmission integrity to sustain unbalanced loads from bent/broken/missing tips.
4. Increased "load-limiting" capacity of seats and fuselage structure to prevent back injury.	4. Crashworthy fuel system.
5. Crashworthy fuel system.	

The above crashworthiness priority list was fairly easy to determine for occupant injury reduction because injury was related to specific deficiencies in most crashes. Use of subjective opinions were necessary in the selection of hardware damage reduction priorities because of the complex interrelation between the factors. For example, the relatively low cost of providing a protected tail rotor combined with the high potential for crash prevention makes its high priority.

c. No new trends have been uncovered in this study which warrant recommendations for change to Military Standard 1290 requirements [5]. This study supports these requirements.

RECOMMENDATIONS

a. Recommend that the results of this study be used by helicopter manufacturers and military Project Manager Offices in decisions regarding crashworthiness requirements versus cost/weight reduction efforts.

b. Recommend that the provisions of Military Standard 1290 be maintained as contractual requirements for the UTTAS aircraft development and procurement.

example, the relatively low cost of providing a protected tail rotor combined with the high potential for crash prevention makes it high priority.

c. No new trends have been uncovered in this study which warrant recommendations for change to Military Standard 1290 requirements [5]. This study supports these requirements.

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9. Personal communication in May 1975 with Mr. Brian Carnell, Sikorsky Aircraft, Stratford, CT.

APPENDIX I

AIRCRAFT CRASH ANALYSIS

Analyzed by:
COMBAT NONCOMBAT Reviewed by:

Case No. __________
Aircraft type ________

Survivability

yes	partially	no

MAJOR IMPACT KINEMATICS
Vert vel _____ft/min
Airspeed _____kt
Impact angle _____deg

TERRAIN
Soft surface
Hard surface
Water
Trees
Other obstacles
Level
Moderate slope
Steep slope

CRASH CONDITIONS

	yes	no
Rolled on impact		
Nosed over on impact		
Lateral (sideward) impact		
Inverted impact		
Severe plowing		
Postcrash fire		
Crashworthy fuel system		

DAMAGE COSTS
Hardware cost: $______________
Cost reductions possible by use of MIL STD 1290 crashworthiness criteria in following areas:
Transmission/rotor/tail rotor $____
Landing gear ____
Tail boom ____
Fuselage, other ____
Crashworthy fuel system ____
Total ____

OCCUPANT INJURIES
Total personnel aboard _______

DUTY POSITION	None	INJURIES: Impact min	maj	fat	Thermal 1st	2nd	3rd	fat	Drowned	HELMET PERFORMANCE: Lost?	Failed?	Reduced Injury?
Pilot												
Copilot												

POOR CRASHWORTHY FEATURES CAUSING INJURY

CRASHWORTHY FEATURE IDENTITY AT OTHERWISE SURVIVABLE DUTY POSITIONS	Condition Present	Primary Injury Cause	Primary Fatality Cause
Inadequate Crash Force Attenuation, General			
" " " " Vert.			
" " " " Long.			
" " " " Side			
Inward Structural Buckling, includes transmission penetration			
Main Blade Penetration of Occupiable Space			
Inadequate Cargo Tiedown			
Inadequate Personnel Restraint			
No Seat Provided			
Seat Provided, not used			